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Longevity of Urediospores of Crown Rust of Oats

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LONGEVITY OF UREDIOSPORES OF CROWN RUST OF OATS

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Crown rust of oats is often the most important factor in the reduction of yields and quality of either oat hay or of grain in Arkansas and in the South as a whole. However, this disease is not always highly destructive, and, while it is seldom absent entirely, it varies considerably in distribution and severity from year to year.

To understand the underlying factors involved in the irregular but rather frequent occurrence of more or less severe epidemics of crown rust, it seemed essential to determine the influence of climatic factors on the variations in the life of the parasite causing this disease. Since the urediospores of *Puccinia coronata avenae* constitute the only spore stage known to be largely or wholly responsible for the dissemination of this parasite in Arkansas, the life span of these spores has been extensively studied under various controlled and uncontrolled combinations of important climatic factors, particularly relative humidity and temperature. A preliminary report *(21)* on these findings has been published.

Review of Previous Investigations

Two different hypotheses are current to explain the yearly appearance of crown rust in the southern parts of the United States. One of these postulates that the parasite lives from one year to another in the uredial stage *(4, 13)*, while the other holds that in at least some parts of the South the rust in most years dies out sometime prior to the appearance of another annual visitation and is renewed by spores blown in from either northern regions in the fall or from more southern regions in the spring *(8)*. Rhamnus spp. are not known to be of importance in perpetuating crown rust in the South *(4, 13)*.

The theory that crown rust overwinters in the South in the uredial stage is by far the one most commonly held. It can be traced through various publications to Carleton *(2)*, who made the following statement in 1899: "Although the writer's opinion is that this rust passes the winter in the uredo [uredial] stage in the warmer latitudes of the United States, there is as yet no good

evidence that it does." The evidence he presented, which he considered to be inadequate, consisted of the observance of uredia and telia of crown rust the first week in March, 1894, on volunteer oats growing at Washington, D. C. The urediospores "were found to be in apparently good condition on leaves not yet dead." He also observed urediospores of both crown and stem rusts on volunteer oats at Manhattan, Kans., up to November 2, 1896.

It is possible that Carleton's opinion was predicated partly on Ericksson's *(7)* findings at Stockholm, Sweden, which were published 3 years prior to his. Ericksson found viable urediopores of *P. coronata* on *Melica nitens* on November 30 in one year and on April 5 in another, but he concluded that under Swedish climatic conditions this rust does not winter to any appreciable extent either as urediospores or as mycelium but as mycoplasm. According to Christman *(3)*, the winter temperatures at Stockholm are similar to those of Madison, Wis.

Following Carleton's publication, Christman *(3)* a few years later made observations on the overwintering in the uredial stage of various cereal rusts, including crown rust of oats at Madison. He found volunteer oats infected with crown rust and showing uredia in the fall of 1902. At various times during the winter, plants bearing uredia were taken indoors, and the spores tested for viability. They germinated on every date collected, the last collection date being on January 26, 1903. The infected plants "were well covered with snow" and artificially protected by mounds of dirt placed at the sides and a pane of glass placed on top of the mounds. Christman concluded that urediospores and mycelium of crown rust were at least as resistant as the oat plants on which they grew. Since the region around Madison is exclusively a spring-oat area, it may be concluded that the volunteer infected oats that Christman studied in all probability would not survive the average winter and early spring under normal conditions of that area. Spring oats in general possess little or no real hardiness. His conclusion, therefore, is fully warranted so far as it goes.

The next significant work on the overwintering of crown rust is that of Reed and Holmes *(18)*. In the fall of 1909, they observed plants infected with crown rust in a plot of volunteer summer oats and in a plot of winter oats, both at Blacksburg, Va., altitude 2,200 feet. Viable urediospores were found on the summer oats throughout the winter up to March 5, despite the fact that the plants were dead December 1. Also viable urediospores were found up to April 1 on the winter oats, the plants

remaining alive throughout, although making growth only up to December 15. Temperature curves, which they presented, indicated mean temperatures above freezing up to January 1 and freezing temperatures from then up to March 1. Minimum temperatures below 20° F. were noted from November 1 up to April 1, the extremes being several degrees above 0° F. No records of humidities were given. Reed and Holmes concluded that the urediospore of crown rust "may and does retain its vitality on winter oats and to a limited extent upon volunteer summer oats" under natural climatic conditions, and concluded similarly for the mycelium in live oat tissue. However, they made no statements relative to the importance of such overwintering of mycelia and urediospores in the initiation of epidemics of crown rust, and apparently made no effort to determine the relationship of the overwintering uredial stage to the presence or amount of crown rust in the following growing season.

There is no doubt that Reed and Holmes have offered the very best evidence up to the present concerning the overwintering of crown rust in the uredial stage. Nevertheless, it is necessary to bear in mind that their work covered only one winter, and that no data or observations were offered on the subsequent development of rust after April 1. Their comment that "*P. coronata* causes little damage as a rule" at Blacksburg leaves much to be determined, especially in large areas of the South where often this rust causes considerable damage.

A number of investigators have dealt with the longevity of urediospores of crown rust, either as detached spores or spores derived from rusted and detached leaves. Fromme *(9)* appears to be the first to have made such studies. In 1913 he reported on two series of investigations. In one series, ripe urediospores were removed from pustules derived from cultures maintained in a greenhouse, and placed in small gelatine capsules, which were then stored "in the laboratory at room temperature." Drop cultures made from time to time up to 48 days of storage yielded 9 to 16 per cent germination. When the spores were tested after 80 days of storage no germination was obtained. In the second series, using the same methods, he obtained germination up to 84 days of storage, although the percentage of germination gradually decreased and at the end equalled only about 0.2 per cent.

Durrell *(6)* in 1918 gave the following data on crown rust urediospores: When placed outdoors in vials during January and February, 1917, at Ames, Iowa, they were not viable after 10 days. When exposed to 5° C., the germination was reduced to 1.5

per cent in 3 days, and all spores were dead in 53 days. At 30 to 35° C. the results were the same, though in the control held at 13 to 20° C., the spores showed 20 per cent germination in the same length of time.

In 1919 Melhus and Durrell *(15)* offered additional data concerning the influence of important climatic factors on the longevity of urediospores of crown rust. They placed rusted oat plants in two glass incubators both maintained at 30° C.; one was kept at 95 per cent relative humidity and the other at 50 to 60 per cent. Unfortunately they limited their germination tests to a period of 5 days, and the percentages of germination which they obtained from one day to the next were so variable that no conclusions could be drawn relative to the influence of humidity on the longevity of the spores. However, they made two other studies on the viability of urediospores, both involving rusted oat plants kept in a greenhouse. In one study they found that the urediospores taken from sori, which were 17 days old, failed to germinate. These sori were on young plants that had died. Contrasted with this, urediospores taken from older plants yielded 17 per cent germination when the sori were 15 days old, even though the leaves were dying because of the maturity of the plants; and 39 days later, when the sori were 54 days old, 12 per cent of the spores remained viable. In another study, urediospores were scraped from pustules into dry capsules that were stored for a period of 55 days at 6, 13, 20, and 30° C. At various intervals, germination tests were made with the following results: At 6° the longest storage period in which viability persisted was 30 days; at 13° the viability persisted for 55 days; at 20° the spores showed 3 per cent viability at the end of 30 days (no data given for 55 days) ; while at 30° only one per cent germination was obtained after 30 days' storage, and none after 55 days.

Hoerner *(10)* in 1921 was apparently the first investigator in the United States to question the efficacy of the uredial stage in carrying crown rust through the winter, either as "perennial" mycelium or as urediospores. Two pots of heavily rusted oat plants were kept outdoors during the winter at St. Paul, Minn. Even before winter, all urediospores had disappeared and only teliospores were in evidence. The plants were winterkilled, and when brought into the greenhouse in April they did not revive.

In additional studies, Hoerner *(11, 12)* presented the following: Urediospores from herbarium specimens of oat leaves were viable 87 days after date of collection. Heavily rusted oat leaves, artificially inoculated in the greenhouse, were placed in

Petri dishes and subjected to the following conditions: Outdoors but protected by a covering one foot thick of leaves and snow; outdoors with no protection; indoors, wrapped in heavy manila paper, and placed in a dark cabinet; and indoors, exposed to sunlight. The results were as follows: Out of five collections subjected to outdoor conditions but protected, two of the collections showed viable spores at the end of 44 days (temperature range, −27 to 42° F. for outdoors, temperatures underneath cover not given); out of four collections placed outdoors and not protected, none showed viability (period of exposure, 22 days); out of two collections kept indoors in the dark, both showed viable spores at the end of 79 days (temperature range, 29 to 86° F.); and out of two collections kept indoors in the sun, neither showed viable spores within 23 days of storage.

In 1924 Maneval *(14)*, in determining the longevity of urediospores of a number of rusts, found that in crown rust of oats urediospores continued to germinate 149 to 164 days after collection. Oat leaves bearing uredia were collected October 18 and November 2, 1923, at Columbia, Mo., on volunteer oats; these were kept at room temperature until November 6, and after drying they were stored in a cool room (5 to 15° C.). Following the remarkable work of Peltier *(17)* on the influence of both temperature and humidity on the life span of urediospores of *Puccinia graminis*, Maneval was among the first to recognize the importance of both of these climatic factors on the longevity of the spores of various rusts.

In 1933 Abe *(1)* working in Japan reported that wheat and oat leaves infected with the uredial stage of *P. triticina* and *P. lolii (P. coronata)*, respectively, were held in a refrigerator at −8 to −9° C. and that a few spores of both rusts retained their vitality after 44 days. Also, "a suspension of urediospores of *P. lolii* was held frozen at the same temperature for 24 hours, by which the germinability of the spores was decreased to about four per cent." (Abe's abstract.)

The most recent work on the longevity of urediospores of crown rust is that of Forbes *(8)*. He found these spores to be short lived at very low or very high temperatures, as well as at 4,[1] 15, and 20° C. At 10° C. they germinated in some instances after 413 days. When dead, rust-infected oat plants were exposed to summer field conditions at Baton Rouge, La., the urediospores did not germinate after 75 days' exposure. He found

[1] Data for the viability of spores at 4° C. are not given in the main body of the report but appear in the summary.

no natural rust infections during the summer or fall, and found none until late December in each of 2 years of observations. He concluded that crown rust urediospores do not survive the summers in Louisiana and that the inoculum must be blown in from other regions to account for the annual occurrence of this rust.

The role of buckthorns (Rhamnus spp.) in perpetuating crown rust is of considerable interest, though indirect, in conjunction with studies on the perpetuation of the rust in the uredial stage. Dietz *(4)* is the only investigator who has made field studies in parts of the South, including Arkansas, of the role of buckthorns in dissemination of crown rust; he also made certain observations on the perpetuation of this rust by means of uredia. "From April 2 to 10, 1919, an extensive field study was made in the vicinities of Fort Smith, Prescott, and Little Rock, Arkansas, to determine whether this shrub [*Rhamnus lanceolata*] was instrumental in starting the annual infection of crown rust in that section. At this time *R. lanceolata* was just coming into leaf and no infection was evident, although uredosori were common in winter oats. As crown rust often lives over winter in Arkansas, this shrub seems to play only a minor role in the initial appearance and subsequent dissemination of crown rust there." Unfortunately Dietz does not present the evidence which convinced him that this rust overwinters in Arkansas. It should be noted that *R. cathartica,* the species which commonly bears æcia in the North-Central States, is very rarely planted in Arkansas and Dietz apparently found none in his field studies in this state.

In a later publication *(5)* Dietz and Leach add the following: "*Rhamnus lanceolata* probably is not an important factor in crown rust dissemination in the winter-oat area, as the urediniospores overwinter throughout most of this area." Murphy *(16)* agrees with Dietz, giving the following evidence. "Except in 1928, forms [races] 1 and 7 were very similar in distribution and prevalence. In that year they were collected from the same regions, but form 1 was much more prevalent. Both forms were found to hibernate on fall-sown and volunteer oats in the South and on the Pacific coast as far north as Astoria, Oreg."

Briefly summarizing the previous work, it appears that no difficulty has been experienced in finding uredia and viable urediospores of crown rust in the fall and early winter in various parts of the United States as far north as Madison, Wis. Likewise, viable urediospores and live crown rust mycelium have been traced through the winter and early spring in Virginia. However, it is not clear that any evidence has been presented which

definitely traced an epidemic of one crop to that of a previous or succeeding crop by means of the urediospores produced in any one field or region. There is need of much additional information relative to the longevity of urediospores and of mycelium under natural climatic conditions as well as under controlled conditions, in order to determine the importance of the uredial stage in carrying the parasite through the summer and winter and initiating rust infections the following growing season.

If the urediospores in any one field or region offer a ready or common means of carrying the parasite from one crop (with or without a volunteer stand) to a succeeding one, as some investigators believe, then in years when the rust is abundant and the spores produced in great quantities, it may be expected that these spores would have greater possibilities of perpetuating the parasite and continuing the epidemic on the succeeding crop. Conversely, in years when crown-rust infections are few and the urediospores produced in limited quantities, there would be a lessened possibility of a severe epidemic on the succeeding crop. If this hypothesis were true, given weather conditions normal or common in large areas of the South, it should be possible to predict severe epidemics several months before they occur and enable the oat grower to practice measures which might counteract the effects of such an epidemic.

This bulletin is restricted wholly to a study of longevity of those urediospores produced under natural conditions on infected plants found in the field during the regular oat-growing season. Studies on rusted volunteer oats found out of season and on oats artificially infected in the fall and carried outdoors through the winter will be reported later.

Climatic Conditions at Main Experiment Station

The University of Arkansas College of Agriculture's Main Experiment Station, where the rust spores used in this investigation were gathered and tested for longevity, is located at Fayetteville, Ark., at an altitude of 1,450 feet, latitude 36°4″. The average yearly rainfall is close to 45 inches, and is fairly well distributed throughout the year. Nevertheless, partly because of relatively high temperatures during July and August, there is quite often a shortage of moisture during these months. United States Weather Bureau records of temperatures and rainfall covering 47 years are given in Table 1.

Relative humidity records, except those obtained by the writers, are not available, but it may be noted in Table 2 that

TABLE 1. AVERAGE TEMPERATURES AND RAINFALL AT FAYETTEVILLE, ARK., U. S. WEATHER BUREAU RECORDS, 1892 TO 1939

Month	Temperatures			Rainfall
	Mean minimum	Mean maximum	Average	
	Degrees F.	*Degrees F.*	*Degrees F.*	*Inches*
January	24.1	52.0	38.0	2.86
February	25.7	54.6	40.1	2.32
March	35.1	63.6	49.3	3.61
April	44.0	72.2	58.1	4.63
May	52.7	79.3	66.0	5.51
June	61.2	87.2	74.2	4.52
July	65.0	91.8	78.4	4.15
August	64.0	92.0	78.0	4.11
September	57.0	85.9	71.4	3.65
October	45.3	75.5	60.4	3.36
November	34.9	63.7	49.3	2.97
December	26.4	52.8	39.6	2.75
Yearly average	44.6	72.5	58.5	44.44

medium to high humidities are common throughout the year. Even in mid-summer when temperatures during the day are high and the relative humidities low, the marked drops in temperature at night, characteristic of the Ozark hilly areas, are almost always accompanied by sharp rises in humidity, frequently reaching the saturation point and resulting in the formation of heavy dews. Thus, the mean or average relative humidity in winter as well as summer is fairly high.

DATES OF PLANTING AND HARVESTING, AND VARIETIES COMMONLY GROWN IN RELATION TO EPIDEMIOLOGY OF CROWN RUST

Both spring- and fall-sown oats are grown in Arkansas, including the region around Fayetteville. Approximately two-thirds of the oat acreage in the state is cut for hay and one-third for grain. The spring-oat crop is planted usually in late February and March and harvested for hay at the end of May; for grain the harvest is about 10 days later. Fall-sown oats, often called winter oats, are planted in September and October, and are cut for hay or grain approximately 2 weeks prior to the spring-oat harvest. Except for volunteer oat plants, no oats are grown in the state during the period of mid-June to mid-September, which is characterized by high temperatures (Table 1) and medium to high humidities. Volunteer oats appearing in the summer months are usually short-lived and are very likely to be winter-killed. Likewise, because of rather frequent shortages of rainfall during the summer, volunteer oats appear much more fre-

quently in the fall at approximately the same time as fall-planted oats than in the summer.

Varieties of the Red Rustproof group constitute approximately 90 per cent of the oat acreage of both spring and fall oats, with such varieties as Ferguson 922, Appler, Nortex, and Ferguson 71 in common use. All of these are characterized by crown-rust-escaping[2] qualities. When grown alongside such varieties as Winter Turf, Lee, Culberson, or Fulghum (varieties constituting most of the remaining acreage) and when crown rust is abundant, they frequently show only 15 to 20 per cent of the leaf areas occupied by rust compared with 90 per cent or more in the others. It is frequently difficult to find uredial pustules on Red Rustproof oats, when crown rust is not abundant, although other commercial varieties ordinarily present no such difficulty. Any attempt to explain perpetuation of crown rust by means of the uredial stage in Arkansas must give due consideration to the fact that the preponderant acreage of both volunteer and cultivated oats belong to the Red Rustproof group.

Materials and Methods

In each of the 2 years in which these investigations were conducted, heavily rusted oat leaves, mostly derived from the variety Markton, were gathered in June prior to the flagging or death of the individual leaves. These leaves, enclosed in paper bags, were immediately placed in an electric refrigerator maintained at 10° C., and a low relative humidity. When thoroughly dried, after about a month, the leaves were cut into small pieces, the pieces placed in open baskets and suspended over the sulphuric acid-water mixtures, which were to govern the degrees of relative humidities required. The method was that previously utilized by the senior author in a study of the longevity of fire-blight bacteria *(19, 20)*.

Pieces of leaves bearing uredia were removed from time to time from the different treatments, the pieces were placed in small beakers containing sterile water, the material thoroughly agitated to free the spores, and the heavy spore suspension atomized on Markton seedlings, the leaves of which had been debloomed by rubbing. The inoculated seedlings were then placed in cloth-enclosed chambers kept moist by means of a constant flow of water. They were kept in this moist atmosphere overnight. The pots

[2] The term rust-escaping rather than rust-resisting is used to indicate a relative freedom from rust under natural field conditions, although under greenhouse conditions the varieties noted show full susceptibility in both type and quantity.

were then held on a greenhouse bench 10 to 14 days, and rust readings taken at the end of that period. This method permitted the testing not only of the viability but also the infectivity of the rust spores. Occasionally the viability was further checked by attempting to germinate the spores directly in water contained in Syracuse dishes and counting the percentages of germination. Such counts, however, were found to be so variable in any one batch of material as to render them quite unreliable. Furthermore, while the method of testing the longevity of spores by inoculating a susceptible variety does not permit an accurate count of the number of infections in terms of the number of spores applied, it does permit a comparative count of the number of infections obtained from the same uredial material and also from differently treated materials. Thus, duplicated pots of inoculated seedlings always showed comparable numbers of infections, with only minor variation. Debloomed seedlings atomized with sterile water and otherwise treated similarly to the inoculated ones were maintained in all of the tests. When such controls showed any crown-rust infections, the results of the whole series were discarded and the tests repeated.

While the use of the field-infected material renders it impossible to confine the tests to only one race of crown rust, investigations revealed that in both years of the testing for longevity, race 1 was by far the most common in the region where the materials were gathered and in the state as a whole as shown in field collections. The differential varieties of oats utilized by Murphy *(16)* for determining the race or races present in any oat material were utilized by the present writers to determine the races present in the rusted oat leaves used for studies on longevity of urediospores, as well as in several hundred collections of rusted oats gathered by the authors in the state. These tests showed that race 1 not only predominated in the material used for studies of longevity, but constituted over 90 per cent of all the other collections. Hence there can be little doubt that the studies on longevity involve race 1 to a very large extent, although the presence of other races in limited quantities is not precluded.

Weather Conditions During the Time of Testing the Longevity of Urediospores

Part of the material subjected to studies of longevity was kept outdoors in a standard United States Weather Bureau instrument house. Prevailing temperatures and relative humidities at the location during the period when the material was exposed are

TABLE 2. OUTDOOR TEMPERATURES AND RELATIVE HUMIDITIES DURING PERIOD OF LONGEVITY TESTS

Year and month	Temperatures: Mean minimum	Temperatures: Mean maximum	Temperatures: Average	Relative humidity averages
	Degrees F.	Degrees F.	Degrees F.	Per cent
1937				
May	56.7	79.4	68.1	67[1]
June	65.4	88.4	76.9	61[1]
July	68.4	90.4	79.4	
August	69.8	91.1	80.5	
September	60.6	80.9	70.8	62[1]
October	46.5	72.8	59.7	
November	33.9	52.9	43.4	
December	30.4	46.3	38.4	---
1938				
January	28.8	50.1	39.5	72[1]
February	39.2	56.2	47.7	64[1]
March	46.4	69.2	[illegible]	
April	49.0	69.3	[illegible]	
May	56.8	76.7	[illegible]	
June	63.5	83.2	73.4	
July	67.9	92.6	[illegible]	
August	70.0	94.3	82.2	68
September	59.7	86.9	73.3	71
October	49.9	81.7	65.8	46
November	37.2	61.2	49.2	62
December	31.5	50.5	41.0	67
1939				
January	34.3	52.9	43.6	72
February	29.6	51.1	40.4	68
March	42.2	64.5	53.4	65
April	45.8	67.7	56.8	68
May	56.1	78.3	67.2	73

[1] Records questionable; readings taken on recording hygrograph which were not checked by sling psychrometer readings.

given in Table 2. Relative humidity readings were made at 8 a. m., 12 m., and 5 p. m. daily, using a sling psychrometer. To avoid lengthy tables of daily records, the humidity records are reduced to mean, or average, records, for each month, calculated by averaging the daily records. With the exception of October, 1938, all months, including the summer months, show a fairly high average relative humidity. Likewise, the average temperatures for the summer months were high, and were higher than those prevailing in the 17-year record (Table 1), but not greatly out of line.

The various combinations of temperature and relative humidity employed, and the results obtained are shown in Table 3. In order to ensure a fair degree of accuracy, the tests in 1937-38 were in large measure duplicated in 1938-39 season, and in addition, a combination at 20° C. with various relative humidities was added.

The data in Table 3 may be interpreted as follows: Under uncontrolled, outdoor temperatures and humidities, the spores

TABLE 3. LONGEVITY OF UREDIOSPORES OF *Puccinia coronata avenae* AT VARIOUS COMBINATIONS OF TEMPERATURE AND RELATIVE HUMIDITY

Temperature	Approximate relative humidity	Comparative number of infections at progressive storage periods						
		1937-38			1938-39			
		100 days	153 days	300 days	15 days	74 days	140 days	301 days
Degrees C.	*Per cent*							
Outdoors	Outdoors	0	0	0	0	0	0	0
Outdoors	0	0	0	0	0	0	0	0
Outdoors	25	0	0	0	+++[1]	0	0	0
Outdoors	50	0	0	0	0	0	0	0
Outdoors	75	0	0	0	0	0	0	0
Outdoors	90	0	0	0	0	0	0	0
5	0	0	0	0	+	0	0	0
5	25	+++	+++	++	+++	++	++	+
5	50	+++	+++	++	+++	+++	+++	+
5	75	0	0	0	+++	++	+	0
5	90	0	0	0	+++	++	0	0
10	0	0	0	0	++	0	0	0
10	25	+++	+	+	+++	+++	+	+
10	50	+++	+	+	+++	++	++	+
10	75	0	0	0	+++	0	0	0
10	90	0	0	0	+++	0	0	0
15	0	0	0	0	++	0	0	0
15	25	+++	+	0	+++	++	0	0
15	50	+++	+	0	+++	+++	+	0
15	75	0	0	0	+++	++	0	0
15	90	0	0	0	+++	0	0	0
20	0				+	0	0	0
20	25				+++	0	0	0
20	50				+++	+	0	0
20	75				++	0	0	0
20	90				+	0	0	0
25	0	0	0	0	0	0	0	0
25	25	0	0	0	++[2]			
25	50	0	0	0	0	0	0	0
25	75	0	0	0	0	0	0	0
25	90	0	0	0	0	0	0	0
30	0	0	0	0				
30	25	0	0	0				
30	50	0	0	0				
30	75	0	0	0				
30	90	0	0	0				
35	0	0	0	0				
35	25	0	0	0				
35	50	0	0	0				
35	75	0	0	0				
35	90	0	0	0				
40	0	0	0	0				
40	25	0	0	0				
40	50	0	0	0				
40	75	0	0	0				
40	90	0	0	0				

[1] +++ = large number of infections, ++ = medium number, + = few infections.
[2] Material accidentally destroyed after storage of 15 days.

lived less than 15 days in the interval between July 21 and August 5, 1938. This was a period of high temperatures and high humidities (Table 2). Under these same uncontrolled, outdoor temperatures but controlled humidities, the only material showing viability at the end of 15 days was that kept at the 25 per cent relative humidity, and even this was no longer alive at the end of 74 days. Consistent with these findings, the 1937-38 tests showed no viability of any spore material kept outdoors in the interval between July 14 to October 22, 1937, a period of 100 days. This interval was characterized by high temperatures during July and August, and moderate ones thereafter.

When the spores were kept at low temperatures of 5 and 10° C. (41 and 50° F.) they were short or long lived, depending upon the relative humidity. In the first series of tests, they lived less than 100 days at 0, 75, and 90 per cent humidity, and remained alive at least 300 days at 25 and 50 per cent relative humidity. The second series of tests gave essentially the same results, the chief difference being that a few of the spores remained viable at the end of 140 days of storage at 5° C. and 75 per cent humidity.

At the temperature of 15° C. (59° F.) spores showed signs of reduced viability at the end of 153 days in the first tests, and at the end of 140 days in the second tests; all were dead at 300 days, even at the most favorable humidities, 25 and 50 per cent.

At comparatively medium and high temperatures of 20, 25, 30, 35, and 40° C. (68 to 104° F.) and at all humidities utilized, the spores were short lived.

The spores kept at 15° C. and 50 per cent relative humidity showed some viability up to 140 days or about 4½ months; if such a combination of weather conditions prevailed in Arkansas from the date of harvest to either the appearance of volunteer oats or the growth of fall-sown oats, it is quite possible that the urediospores of one crop would offer a potential source of infection for the succeeding one. However, the data in Table 3 suggest that as the temperature rises above 15° and the humidity above 50 per cent, the longevity of the spores is proportionately reduced, so that at 20 and 25° C. (68 and 77° F.) the spores at all humidities are comparatively short lived. The average temperatures of June, July, and August in this region are 74 to 78° F. (Table 1).

The data throughout the series of tests show that humidity as well as temperature influence the longevity of spores to a marked degree.

Interpretation of Results

There are a number of questions to be raised relative to the applicability and interpretation of the methods and results; among these are the placement of the rusted leaves in a relatively dry refrigerator immediately after they were gathered. There are two reasons for such treatment. First, it should, if possible, represent more or less ideal conditions for the perpetuation of vitality. Second, unless all the material were brought to a fair degree of uniformity, especially in humidity and temperature, prior to their placement under different combinations of temperature and humidity, there could be no adequate comparison of the effects of the different treatments. So far as the drying effects of this treatment are concerned, they are perhaps not greatly different from those obtained in making hay and storing it in a barn, or from the drying obtained in the outside layers of a straw stack. The refrigeration temperature of 10° C. (50° F.) is, however, quite unlike that which is likely to occur in a barn during the summer or in a hay stack. There is no doubt that the pretreatment of the material for several weeks at 50° F. introduces a distinctly artificial condition. Nevertheless, it is believed that any change brought about in the material by this relatively short storage was not sufficiently great to vitiate the results obtained. Furthermore the change may be considered as having an effect of prolonging the life of the urediospores, rather than shortening it, in view of the final results obtained.

Another question concerns the applicability of placing part of the material for outdoor conditions in a standard United States Weather Bureau instrument-type house. Such housing must affect the material very considerably, so far as the influences of sun, rain, and wind are concerned. However, since most of the oats grown in this state are harvested for hay, as previously noted, and the remainder for grain, it is clear that the conditions desired should duplicate those obtained in a haymow or in a straw stack as far as possible. The use of weather bureau-type housing, it was thought, would duplicate in some degree at least the conditions in a barn; hence, strictly speaking, such housing would not provide unsheltered, outdoor conditions. Likewise, it would certainly not duplicate conditions in a straw stack. However, so far as the latter is concerned, variation in temperature, humidity, and microflora between the outside and inside layers of straw would be so great that it would be very difficult to duplicate such conditions and still have them under experimental

control. Considering the results obtained under controlled conditions of temperature and humidity, there is little doubt that crown-rust urediospores are short lived under conditions that are likely to exist in a straw stack.

While the data indicate that combinations of fairly low temperatures and low or medium humidities are required for long life spans of the urediospores of crown rust, they also show that such combinations usually are not to be had under Arkansas conditions for any length of time and at any season of the year. Especially is there very little likelihood for such weather combinations during the interval from the time of harvest up to growth of the succeeding oat crop. The results show conclusively that urediospores gathered about the time of oat harvest are short lived under the weather conditions existing in the state, and, hence, are consistent with the data obtained under controlled temperatures and humidities.

Considering the data presented, there is, therefore, abundant evidence for the conclusion that, so far as race 1 of crown rust is concerned, the urediospores produced on any one oat crop are not able to live long enough under Arkansas conditions to perpetuate the disease on the succeeding crop.

There remains the possibility of volunteer oats or other susceptible grasses carrying the disease in the uredial form on live plants from one oat crop to another in the South, but evidence for this does not exist and Forbes' *(8)* data, obtained in Louisiana, lend no encouragement for this assumption. However, much additional work is necessary before it is entirely excluded.

Summary and Conclusions

In a study of the life cycle of *Puccinia coronata avenae* in Arkansas, one of the questions to be answered was the importance of urediospores produced in a given locality in carrying the parasite from one crop season to another in the same general locality. In an attempt to answer this question, oat leaves heavily infected with the uredial stage were subjected to uncontrolled, natural conditions of temperature and humidity, as well as to 45 different combinations of controlled temperature and humidity. The range in temperature was from 5° C. (41° F.) to 40° C. (104° F.), and in relative humidity from approximately 0 to 90 per cent.

Urediospores gathered in June and kept outdoors under natural conditions of temperature and humidity were found to be short lived, living less than 15 days. During each of the 2 years in which these tests were conducted, the average temperature and

humidity were high and were characteristic of average conditions in Arkansas at that season.

Under controlled conditions, spores kept at comparatively low temperatures, 5 and 10° C., and low humidities, 25 and 50 per cent, showed greater longevity than those at higher temperatures or higher humidities. The difference in life span was very marked, ranging from less than 15 days under the higher temperatures and humidities to over 300 days under the lower conditions.

Humidity as well as temperature was found to influence longevity to a marked degree. Thus, below 25 per cent or above 50 per cent relative humidity, the spores were found to be short lived, irrespective of temperature.

The evidence here presented indicates that no predictions are possible of the severity of crown rust on a future crop based on the prevalence of rust on the current crop, so far as longevity of urediospores is concerned.

It is concluded that, so far as race 1 of crown rust is concerned, the common race prevalent in Arkansas, the urediospores produced on one oat crop are incapable of living long enough to perpetuate the disease on the succeeding crop under the climatic conditions here existing, and that additional work is necessary to determine the sources of infection.

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